Sensitivity Analysis of Tall Buildings in Semarang Due to Fault Earthquakes with Maximum 7 Mw

by Windu Partono

Sensitivity Analysis of Tall Buildings in Semarang, Indonesia Due to Fault Earthquakes with Maximum 7 Mw

Windu Partono[1, a)], Bambang Pardoyo[1, b)], Indrastono Dwi Atmanto[1, c)], Lisa Azizah[1, d)] and Rouli Dian Chintami[1, e)]

[1]Civil Engineering Department, Diponegoro University. 50275 Semarang, Indonesia

[a)]windu_bapake_dila@yahoo.com
[b)]indrastono.dwiatmanto@gmail.com
[c)]bambang_pardoyo@yahoo.com
[d)]lisaazizah@rocketmail.com
[e)]dian_chintamis@yahoo.com

1. INTRODUCTION

Sensitivity analysis of building structure is one of the important methods use for evaluating the stability and stiffness of structure. Sensitivity analysis is an analysis method for evaluating the stability and stiffness of buildings by conducting gradually increasing or decreasing loads or special loads to building structure. The objective of the analysis is to get the information of maximum loads that can be applied to one building. A lot of parameters can be used to evaluate the stability and stiffness of building. Stability of tall buildings usually performs by calculating deformation and inter-story drift and comparing it with the permissible maximum deformation and drift ratio values proposed by national or international codes. Design of tall buildings usually performs by conducting specific loads or combine loads to obtain the information of size and detail information of structure elements to be built. Engineers usually do not care with restrain capability of structure against improve loads. Seismic loads is one of the important loads should be taken into account for evaluating the stability and stiffness of buildings.

Design for inter-story drift and lateral stability is an issue which should be addressed in the early stages of design development. This paper presents the sensitivity analysis of tall buildings against seismic loads. The analysis was performed by conducting special seismic loads produces by specific earthquake with specific magnitude and distance between the buildings with earthquake source positions. A deterministic approach was performed to evaluate deformation and drift ratio of 8 (eight) tall buildings with minimum 40 meter high. All buildings are located in Semarang and were designed and built using [1 and 2].

Following the research conducted by Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, 5 (five) shallow crustal fault earthquake sources are located less than 50 Km distance to Semarang. Semarang Fault and Lasem Fault are two earthquake sources which crosses the study area. Fig. 1 shows the position of 5 closest seismic sources surrounding the study area. Fig. 2 shows the position of 8 buildings (reinforced concrete building) against Semarang Fault. Fig. 3 shows the position of 8 buildings against Lasem Fault. Fig. 4 shows the position of 8 buildings against Demak Fault

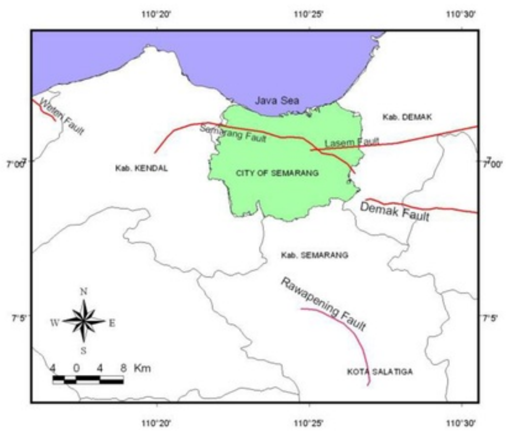

Fig. 1. Five closest seismic fault sources trace

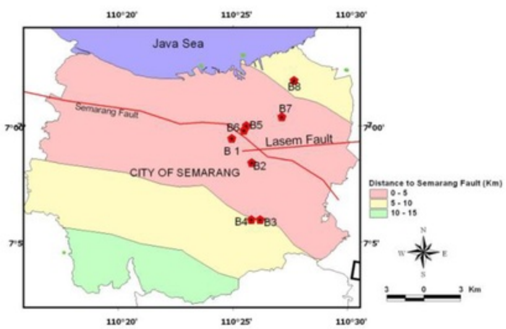

Fig. 2. Position of all buildings against Semarang fault

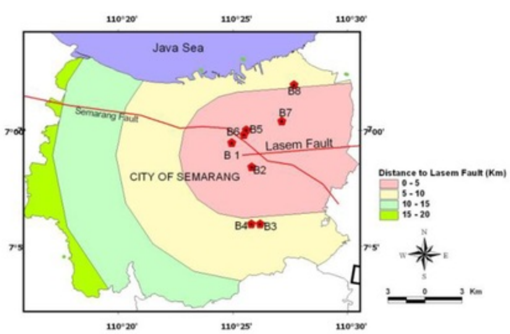

Fig. 3. Position of all buildings against Lasem fault

Following research on seismic microzonation conducted by [3] and engineering suggestion from Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, Deterministic seismic approach was implemented by conducting shallow crustal fault earthquake sources with magnitude in between 6 to 7 Mw and maximum distance 20 Km from predicted seismic source location. Three seismic sources (Lasem Fault, Semarang Fault and Demak Fault) are to be taken into account for stability evaluation of all buildings.

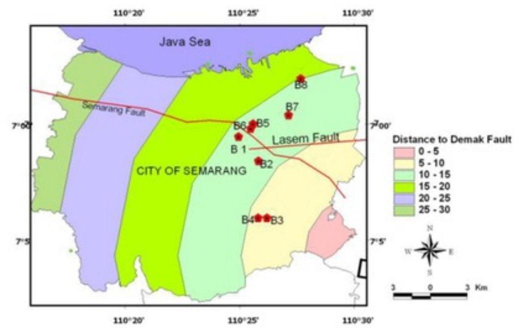

Fig. 4. Position of all buildings against Demak fault

2. GEOTECHNICAL CONDITIONS

Semarang is the capital city of Central Java Province. The city has an area of about 374 square kilometres. Based to on the topographic relief, the city can be divided into two different regions, a coastal plain area in the northern part with maximum 5% slopes and the hilly area in the center and southern parts with maximum 33% slope.

Site characterization (classification) of geotechnical data were carried out by [3 and 4] by interpreting the results of soil boring investigations at 288 locations with minimum 30 meter depth. In-situ standard penetration test (N-SPT) were collected for each boring locations to identified Vs30 value (average shear wave velocity at top 30 meter soil layer). Vs30 value was calculated and estimated following the same method proposed by [2] using équation (1) where 'd_i' and 'Vs_i' represent thickness and shear wave velocity of each layer respectively. The Vs values for each soil layer were estimated using N-SPT value and conducting three empirical correlation equations proposed by [5, 6 and 7].

$$Vs30 = \frac{30}{\sum_{i=1}^{N} \frac{di}{VSi}} \tag{1}$$

Based on all Vs30 values calculated at 288 locations, Vs30 map of the study area was then developed. Fig. 5 shows the distribution of Vs30 values for the whole area of the city. The corresponding site class map was implemented using all 288 Vs30 values and following the same method proposed by [2]. Fig. 6 shows the distribution of site class. Based on this site class map, the positions of each building in terms of site class can be predicted. Building no B7 and B8 are located on site class SE. Building no B1, B2, B5 and B6 are located on site class SD. Hence building no B3 and B4 are located on site class SC.

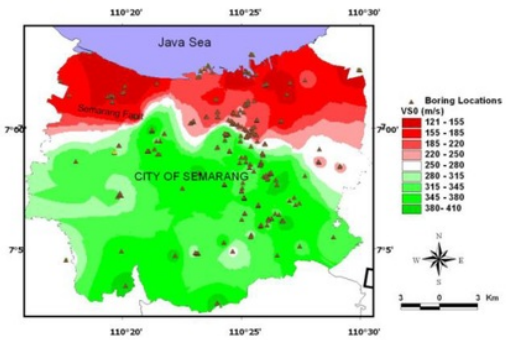

Fig. 5. Contour map of Vs30 and boring locations

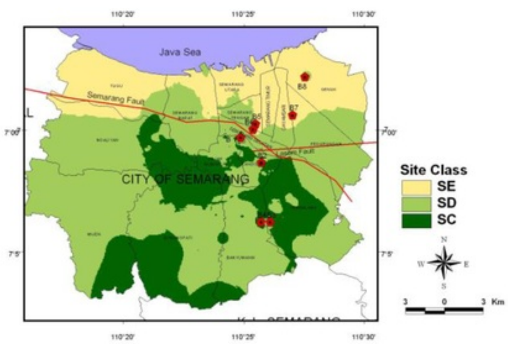

Fig. 6. Site class map building locations

3. DEVELOPMENT OF ACCELERATION TIME HISTORIES

Based on the research proposed by Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, Lasem Fault is typical strike slip earthquake mechanism source hence Semarang and Demak fault are typical reverse earthquake mechanism sources. Both typical mechanism earthquake sources have different method on producing earthquake wave. Based on these two different mechanism earthquakes, acceleration time histories develop from those two earthquakes are also different.

Ongoing research on seismic microzonation of this city identified 17 (seventeen) modified acceleration time histories which can be used for dynamic analysis of building structure. Those 17 modified acceleration time histories were developed for strike slip earthquake. However there are another 15 (fifteen) modified acceleration time histories were developed for reverse fault earthquake. Following the suggestion from Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, earthquake with magnitude 6.5 Mw must be taken into account for seismic mitigation for Semarang.

Due to the limited earthquake records of Lasem Fault, Semarang Fault and Demak Fault earthquakes with magnitude 6.5 Mw, acceleration time histories used in this study were collected from worldwide ground motion databases. All acceleration time histories from historical earthquake with magnitude from 6 to 7 Mw and maximum distance 20 km were collected from PEER NGA-West 2 databases.

Acceleration time histories used in this study depends on the position of each building against fault trace. Table 1 shows minimum distance of each building to fault trace where DLF, DSF and DDF represents minimum distance to Lasem Fault, Semarang Fault and Demak Fault respectively. Table 2 shows acceleration time histories used for each building due to Lasem Fault earthquake. Table 3 shows time histories data due to Semarang Fault and Demak Fault earthquake.

Table 1. Minimum distance of each building to fault trace.

Building No.	Site Class	DLF (Km)	DSF (Km)	DDF (Km)
B1	SC	1.38	0.65	13.80
B2	SC	0.92	1.16	11.37
B3	SC	5.44	4.98	8.45
B4	Sc	5.40	5.11	9.11
B5	SD	2.03	0.85	13.75
B6	SD	1.65	0.42	13.58
B7	SE	2.51	3.13	12.69
B8	SE	5.31	5.94	14.90

Table 2. Time histories for reverse fault earthquake

Earthquake	**Station**	**M (Mw)**	**R (km)**
Northridge-02 (1994)	Arleta - Nordhoff Fire Sta	6.05	1.48
	Newhall - Fire Sta	6.05	7.36
	LA - Century City CC North	6.05	18.34
Chi-Chi, Taiwan-03 (1999)	TCU084	6.2	3.68
	TCU089	6.2	5.93
	TCU076	6.2	13.04
Northridge-01 (1994)	Arleta - Nordhoff Fire Sta	6.69	3.3
	Beverly Hills - 14145 Mulhol	6.69	9.44
	LA - Brentwood VA Hospital	6.69	12.92
Chuetsu-oki, Japan (2007)	Nagaoka	6.8	3.97
	Kashiwazaki City Takayanagicho	6.8	10.38
	Yan Sakuramachi City watershed	6.8	12.98
Iwate, Japan (2008)	IWTH24	6.9	3.1
	IWT011	6.9	8.41
	Kurihara City	6.9	12.83

M = seismic magnitude; R = Epicentral distance

Table 3. Time histories for strike-slip fault earthquake

Earthquake	Station	M (Mw)	R (Km)
Imperial Valley (1979)	El Centro Array #8	6.53	3.86
	Chihuahua	6.53	7.29
	El Centro Array #11	6.53	12.56
Chi-Chi Taiwan (1999)	CHY074	6.2	6.02
	CHY080	6.2	12.44
Kobe, Japan (1995)	Nishi-Akashi	6.9	7.08
	Nishi-Akashi	6.9	7.08
	Amagasaki	6.9	11.34
Victoria Mexico (1980)	Victoria Hospital Sotano	6.33	6.07
	Cerro Prieto	6.33	13.8

M= Seismic Magnitude; R = Epicentral distance.

The acceleration time histories collected from worldwide databases should be checked and need matches with predicted earthquake produce by local seismic source. Surface acceleration time histories can be developed following two basic analysis such as response spectral matching and site response analysis. The first analysis related with matching proces of time histories collected from worldwide databases with predicted spectral acceleration time histories from local earthquake source. The second proses related with propagation of ground motion in terms of acceleration time histories from bedrock position to earth surface. Surface acceleration time histories developed from those two analysis can be used for dynamic structural analysis. Fig. 7 shows surface time histories modified from Northridge-02 earthquake with magnitude 6.69 Mw and epicenter distance 3.3 Km. Fig. 8 shows surface time histories modified from Northridge-02 earthquake with magnitude 6.69 Mw and epicenter distance 9.94 Km. Fig. 9 and Fig 10 shows two surface time histories developed from Kobe earthquake with magnitude 6.9 Mw and epicenter distance 9.94 Km and 7.08 Km respectively.

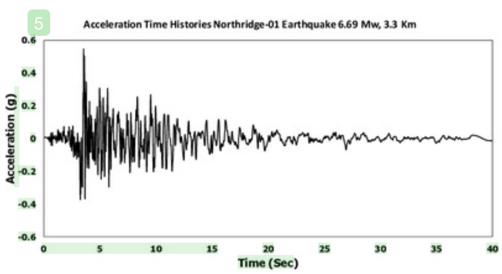

Fig. 7. Acceleration time histories Northridge-02 earthquake, M = 6.69 Mw R = 3.3 Km

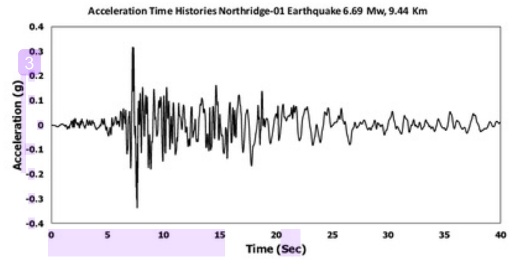

Fig. 8. Acceleration time histories Northridge-02 earthquake, M = 6.69 Mw R = 9.94 Km

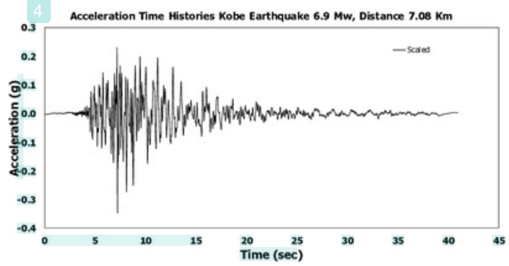

Fig. 9. Acceleration time histories Kobe earthquake, M = 6.9 Mw, R = 7.08 Km

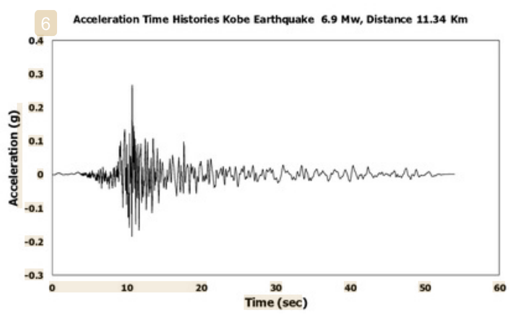

Fig. 10. Acceleration time histories Kobe earthquake, M = 6.9 Mw, R = 11.34 Km

4. STRUCTURAL ANALYSIS

The structural analysis was performed by conducting 3D analysis of model structure to get the deformation and inter-story drift ratio of each floor elevation. Combine force live load, dead load and seismic force were implemented for each building. Seismic force was implemented by conducting two model earthquake force, response spectra and time histories function. Acceleration response spectra used in structural analysis developed from surface spectra conducting by [2]. Fig. 11 shows 8 (eight) surface spectra used for each building and obtained from online facilities prepare by [8].

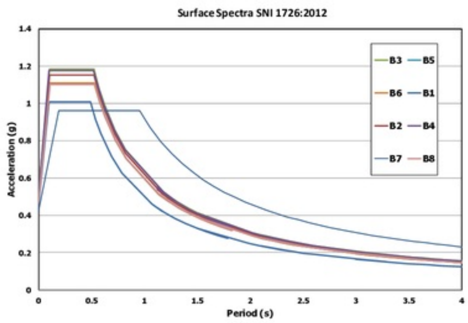

Fig. 11. Surface response spectra [2]

Surface response spectra obtained from [2] are then compared with spectra acceleration developed from propagation analysis or site response analysis. Site response analysis was performed to obtain surface response spectra developed from acceleration time histories. Site response analysis was performed using the constitutive model proposed by [9 and 10] and utilizing the free software NERA [11]. The propagation analysis had been performed using Equation (2), where ρ is soil density, η is viscosity and G is shear modulus of soil. Fig. 12 shows surface response spectra calculated using [2] and surface acceleration histories. Fig. 13 shows drift ratio calculated using [2] and acceleration time histories.

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t} \qquad (2)$$

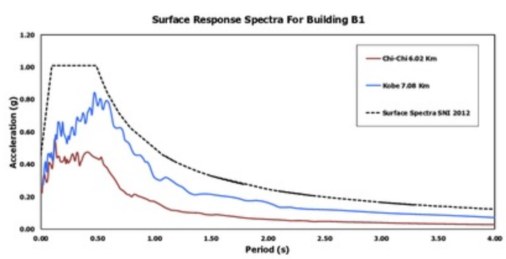

Fig. 12. Surface response spectra calculated from [2] and surface spectra calculated from acceleration time histories

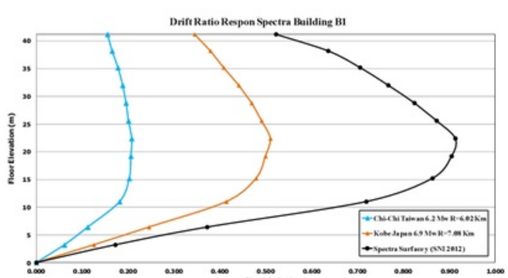

Fig. 13. Drift ratio calculated using surface response spectra [2] and surface acceleration time histories

5. RESULT AND DISCUSSION

Deformation and inter-story drift calculated using surface spectra acceleration from [2] can be compared with the same value calculated using surface acceleration time histories. Drift ratio and deformation of building calculated using acceleration time histories is less than the same value calculated using [2] when surface response spectra calculated using acceleration histories is less than surface response spectra calculated using [2]. Fig. 14 shows surface response spectra calculated using [2] and acceleration time histories. Fig. 15 shows corresponding drift ratio result calculated using [2] and acceleration time histories.

Stability of building structure can be predicted based on surface spectra. If surface spectra calculated using [2] is less than surface spectra calculated using acceleration time histories, the structure will not strong enough to resist the deformation from specific earthquake. Fig. 16 show the surface spectra for building no B3 calculated using [2] is less than surface spectra calculated using acceleration time histories produced by Imperial Valley earthquake with magnitude 6.53 and epicentre distance 3.86 Km. Deformation of building B3 calculated using acceleration time histories from Imperial Valley earthquake is greater than deformation calculated using [2]. Building B3 is not strong enough to resist earthquake force produced by Imperial Valley earthquake with magnitude 6.53 Mw and epicentre distance 3.86 Km.

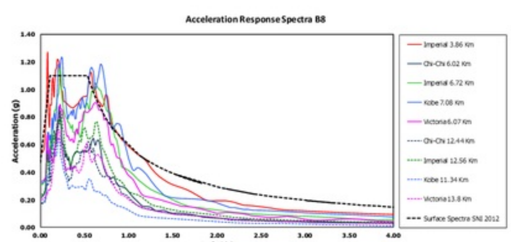

Fig. 14. Surface spectra calculated using [2] and acceleration time histories

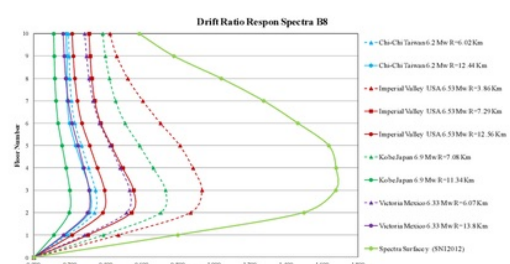

Fig. 15. Drift ratio of building B8 calculated using [2] and acceleration time histories.

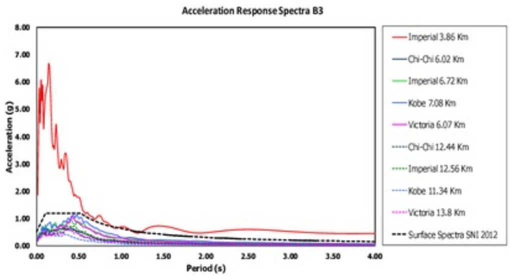

Fig. 16. Surface acceleration time histories of building no B3.

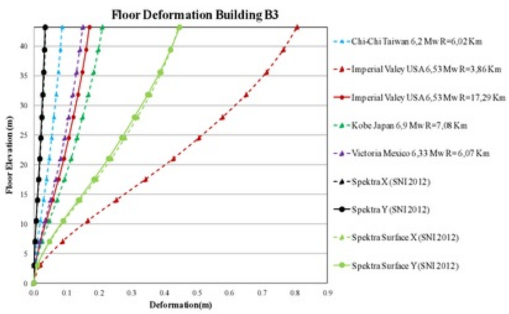

Fig. 17. Deformation of building no B3.

6. CONCLUSIONS

Sensitivity analysis of building against earthquake can be predicted by evaluating surface responses spectra calculated using seismic code and surface response spectra calculated from acceleration time histories. If surface response spectra calculated using seismic code is greater than surface response spectra calculated from acceleration time histories the structure will stable enough to resist the earthquake force.

Based on the evaluation of 8 building in Semarang, all building will not strong enough to resist earthquake force produced by earthquake with magnitude more than 6.5 Mw and epicentre distance to building position less than 5 Km.

Sensitivity Analysis of Tall Buildings in Semarang Due to Fault Earthquakes with Maximum 7 Mw

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

Sensitivity Analysis of Tall Buildings in Semarang Due to Fault Earthquakes with Maximum 7 Mw

ORIGINALITY REPORT

15%	6%	7%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universitas Diponegoro Student Paper	6%
2	Irsyam, Masyhur, Daniel Hutabarat, M Asrurifak, Iswandi Imran, Sri Widiyantoro, Imam Sadisun, Bigman Hutapea, Taufik Afriansyah, and Haris Pindratno. "Development of seismic risk microzonation maps of Jakarta city", Geotechnics for Catastrophic Flooding Events, 2014. Publication	1%
3	www.scribd.com Internet Source	1%
4	www.partnershipsbc.ca Internet Source	1%
5	scholar.lib.vt.edu Internet Source	1%
6	www-2.unipv.it Internet Source	1%

7 amsdottorato.unibo.it
Internet Source
1%

8 Otani, Akihito, Izumi Nakamura, and Hajime Takada. "Simplified Elasto-Plastic Response Analysis Method of Piping", Elevated Temperature Design and Analysis Nonlinear Analysis and Plastic Components, 2004.
Publication
1%

9 Boon-Teck Ooi. "Managing zero sequence in voltage source converter", Conference Record of the 2002 IEEE Industry Applications Conference 37th IAS Annual Meeting (Cat No 02CH37344) IAS-02, 2002
Publication
<1%

10 Radu Popescu. "Finite element assessment of the effects of seismic loading rate on soil liquefaction", Canadian Geotechnical Journal, 04/2002
Publication
<1%

11 Vahdani, Shahriar, John Egan, Robert Pyke, Ariyaputhirar Balakrishnan, Chin-Cheng Chin, Kenny Ogunfunmi, and Tom LaBasco. "Seismic Microzonation Study at the Port of Oakland", Ports 2004, 2004.
Publication
<1%

12 Zareei, Seyed Alireza, Mahmood Hosseini, and Mohsen Ghafory-Ashtiany. "Evaluation of
<1%

power substation equipment seismic vulnerability by multivariate fragility analysis: A case study on a 420kV circuit breaker", Soil Dynamics and Earthquake Engineering, 2017.
Publication

13	www.ebmud.com Internet Source	<1%
14	peer.berkeley.edu Internet Source	<1%
15	ec.europa.eu Internet Source	<1%
16	Waezi, Zakariya, and Fayaz Rofooei. "Stochastic Non-Stationary Model for Ground Motion Simulation Based on Higher-Order Crossing of Linear Time Variant Systems", Journal of Earthquake Engineering, 2016. Publication	<1%
17	Ahmed Nisar. "Seismic Design Criteria for the Maleo Producer, Madura Straits", Proceedings of Offshore Technology Conference OTC, 05/2008 Publication	<1%
18	M. H. T. Rayhani. "Nonlinear Analysis of Local Site Effects on Seismic Ground Response in the Bam Earthquake", Geotechnical and Geological Engineering, 02/2008 Publication	<1%

19 Buratti, Nicola <1980>(Savoia, Marco). "Assessment of Seismic Safety: Response Surface Approach and Accelerogram Selection Issues", Alma Mater Studiorum - Università di Bologna, 2011. <1%

Publication

20 Li, Rui Shan, and Xiao Ming Yuan. "Verification of LSSRLI-1 Applicability on Soft Sites Using Exact Solution", Applied Mechanics and Materials, 2014. <1%

Publication

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	On		